The Argon Geochronology Experiment (AGE)

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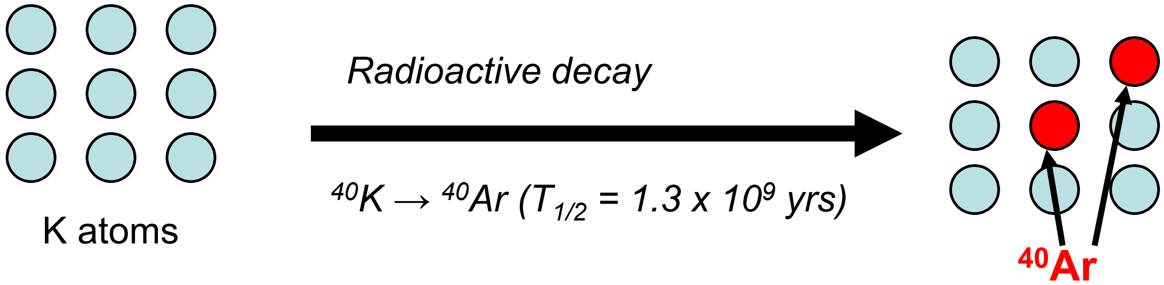
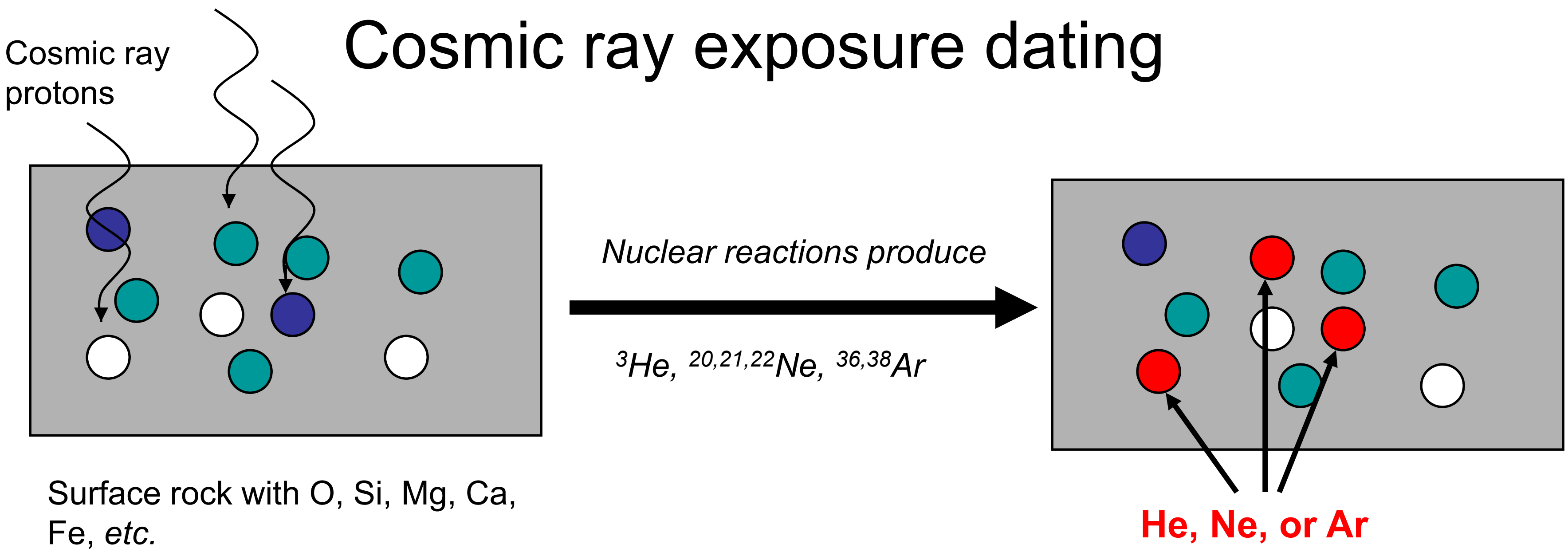
K-Ar dating



Measure abundance of K, ^{40}Ar; Calculate time since last thermal event

Cosmic ray exposure dating



Measure abundances of O, Si, Mg, Ca, Fe, etc., ^{3}He, ^{20,21,22}Ne, ^{36,38}Ar.
Calculate time within ~1m of surface where reactions have occurred.

AGE flow diagram

Acquire sample, load into crucible.

⇩

Do LIBS analysis for elemental abundances.

⇩

Load sample into vacuum, pump down.

⇩

Melt sample, release gas, getter non-noble species.

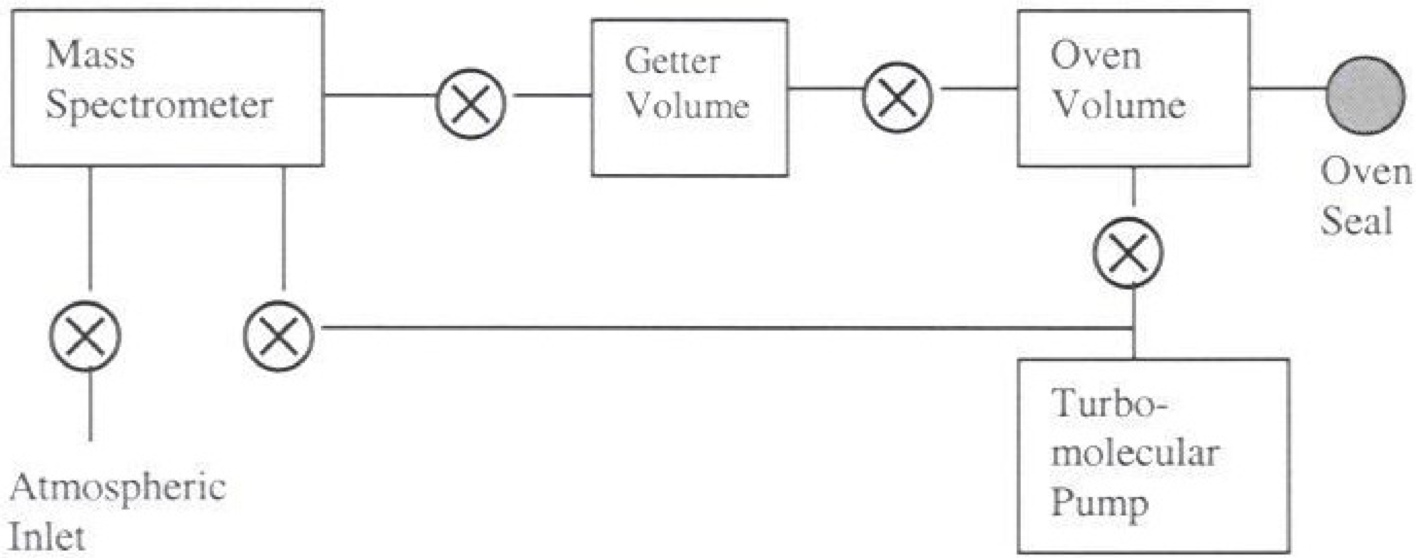
⇩

Analyze gas (Paul trap).

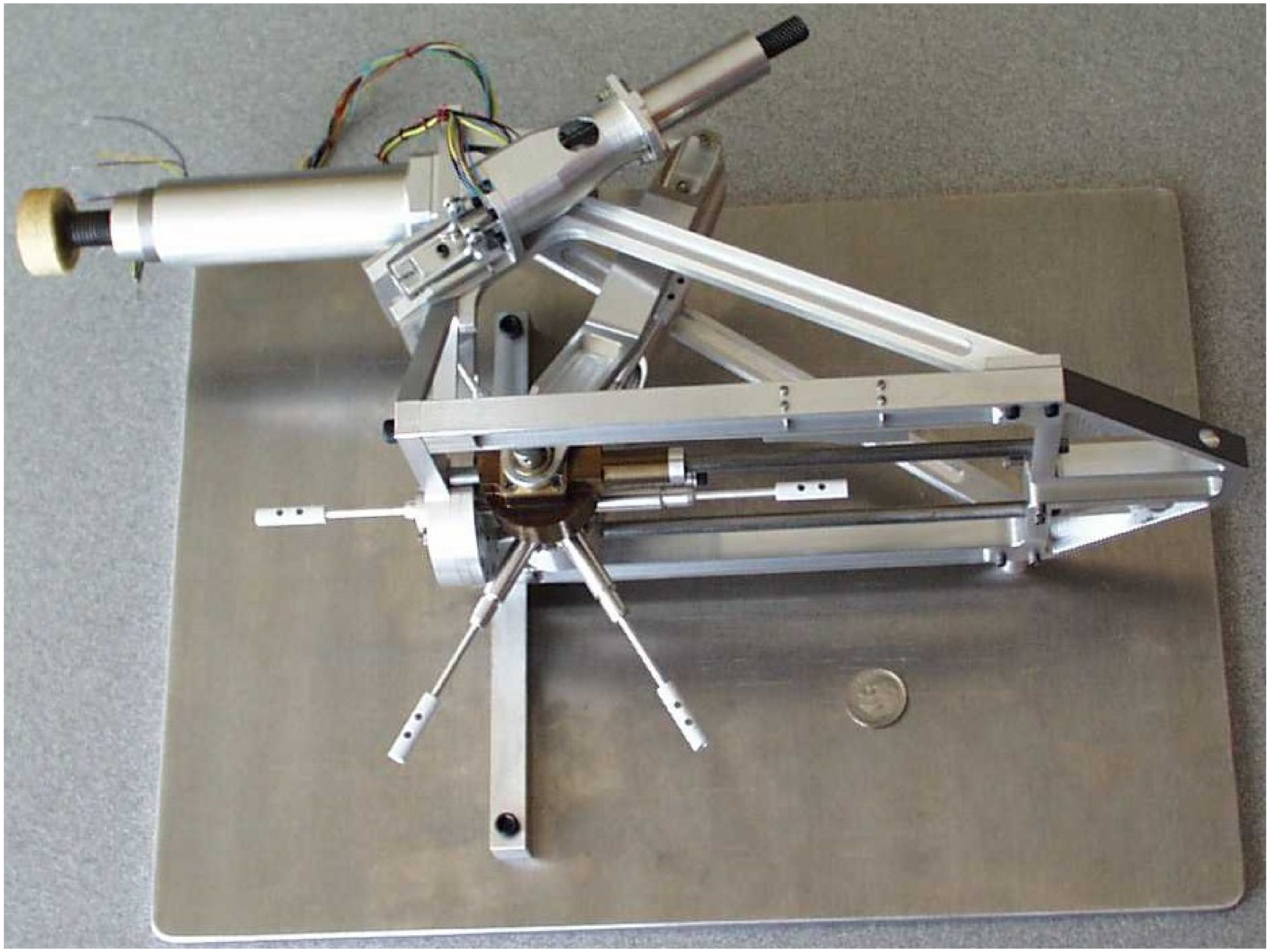
⇩

Measure volume, calculate mass.

Vacuum System Schematic

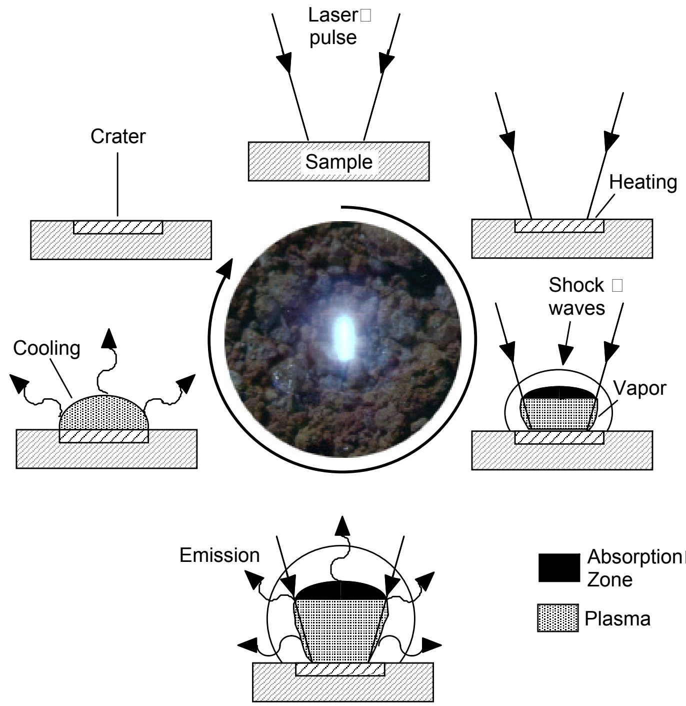


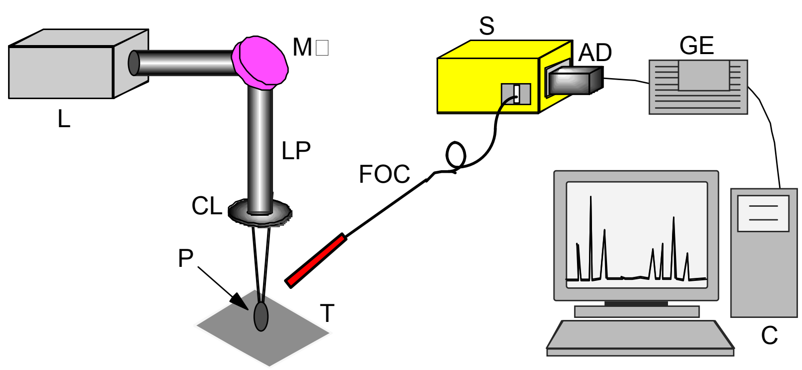
Sample Manipulation Mechanism



Samples are contained in the "dimples" visible on each arm. Sample loading is to the right, the vacuum system (not attached) to the left.

Operation of the LIBS Instrument



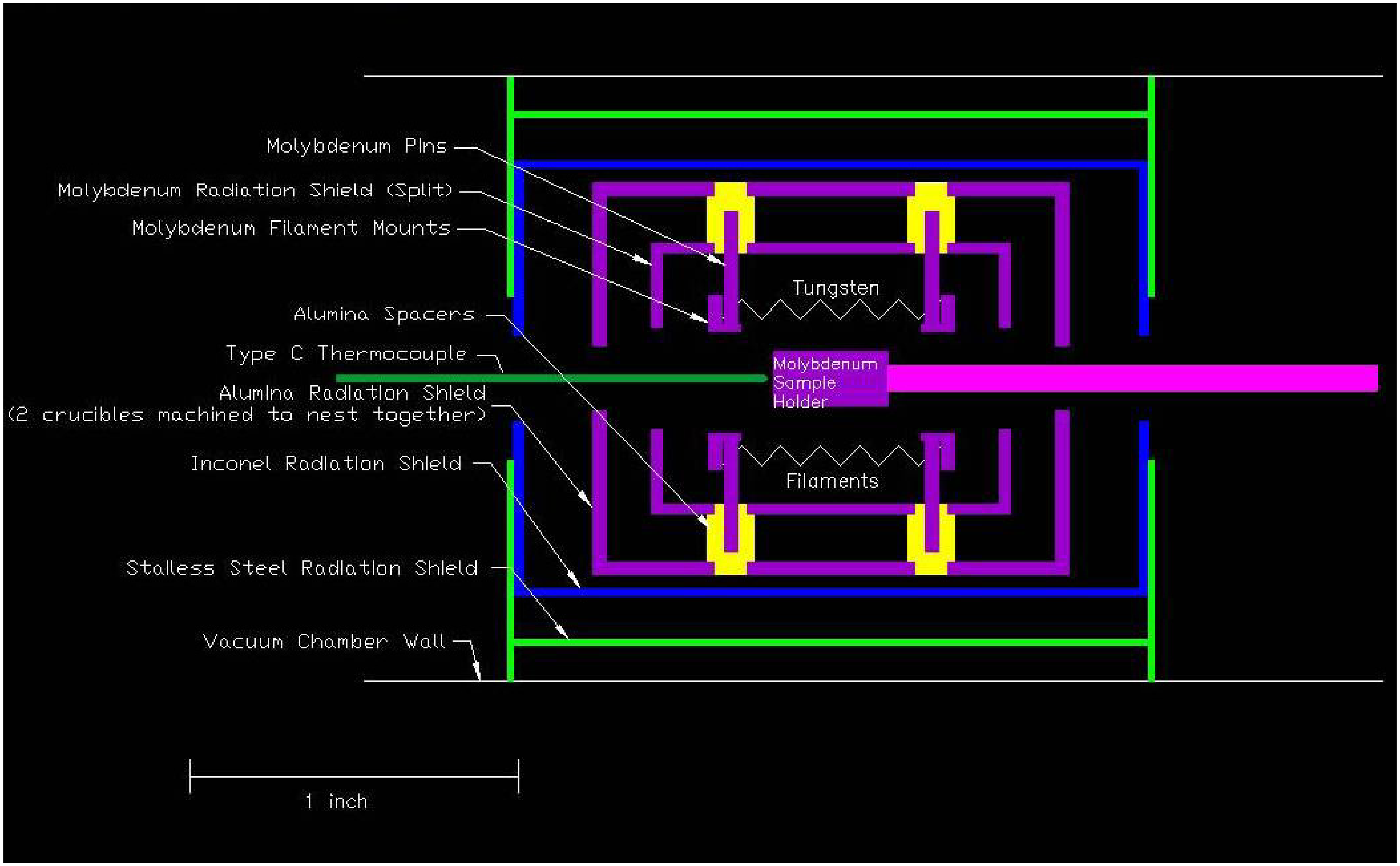


Components of the LIBS Instrument

L = Nd:YAG laser	**FOC = fiber optic**
M = mirror	**S = spectrograph**
LP = laser pulse	**AD = array detector**
CL = lens	**GE = electronics**
P = plasma	**C = computer**

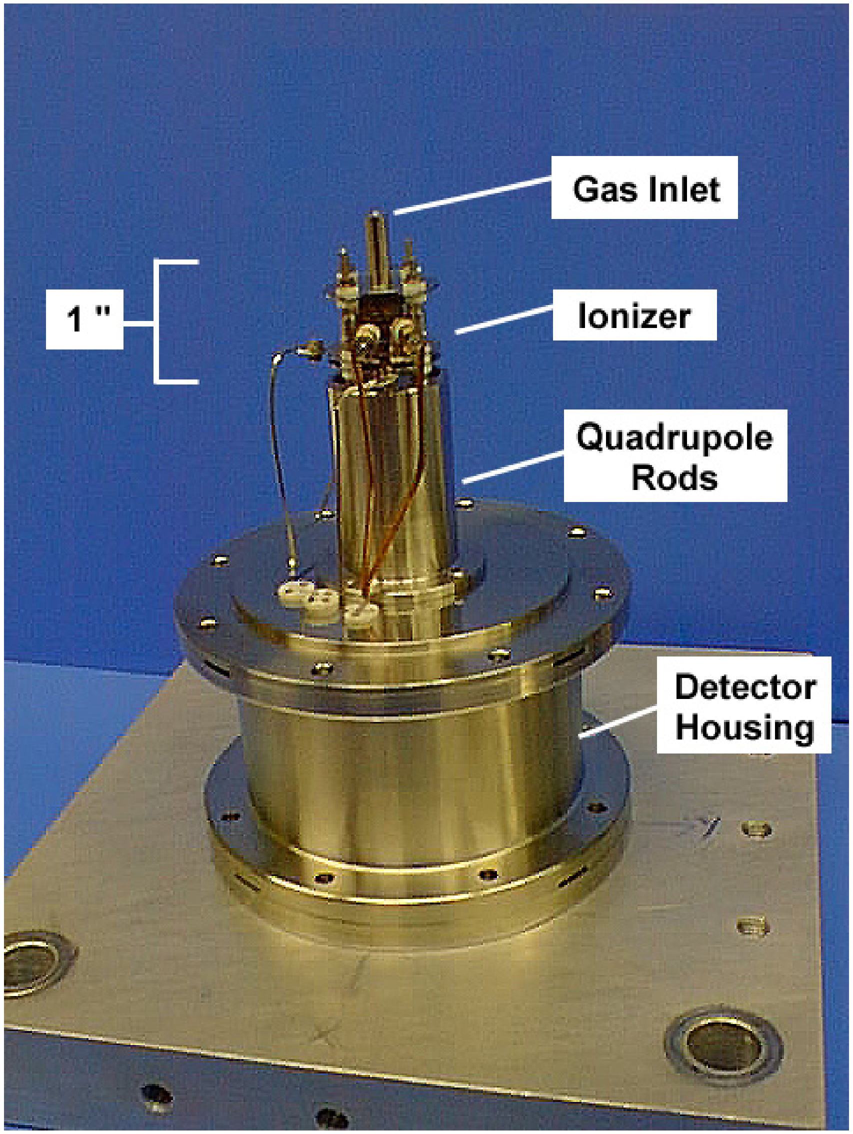
T = target

Schematic of the Mineral Heater Oven



Heating is via six tungsten filaments (two shown). The series of radiation shields makes it possible to achieve a sample temperature of 1500C with minimal radiation losses.

QMSA Sensor Overview



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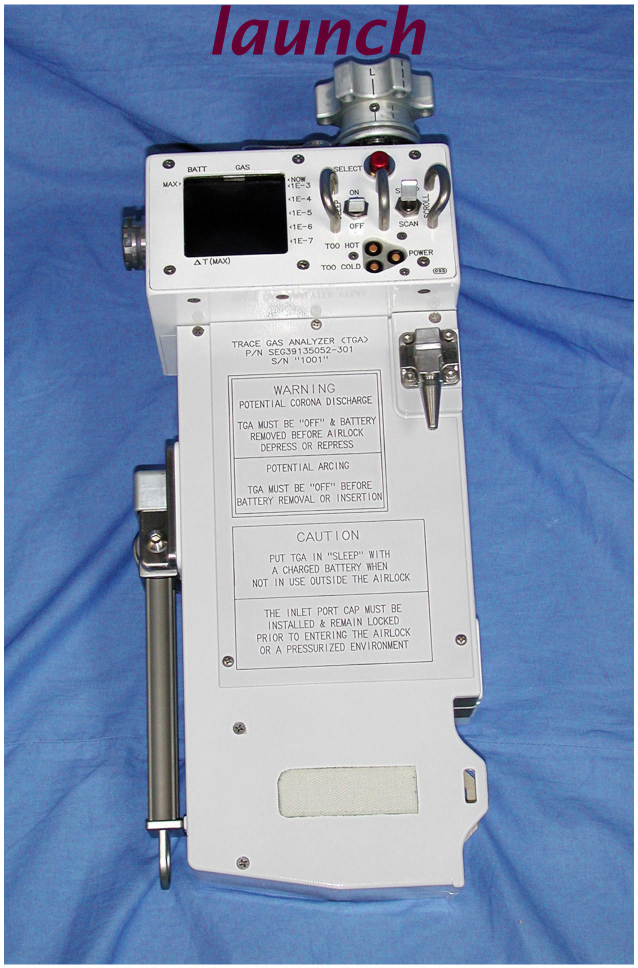
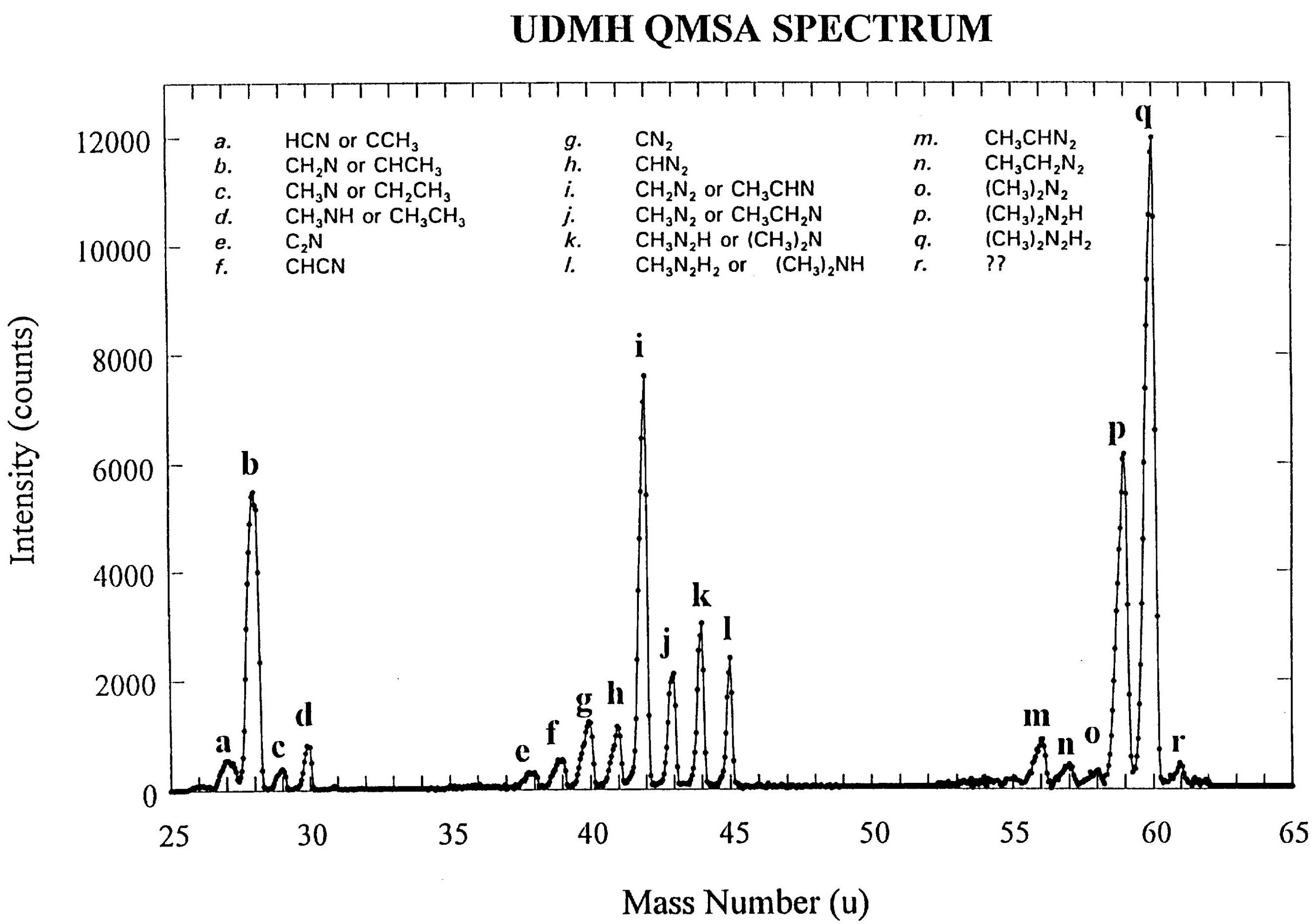
The packaged TGA prior to launch



The TGA on ISS

Results … mass spectra …



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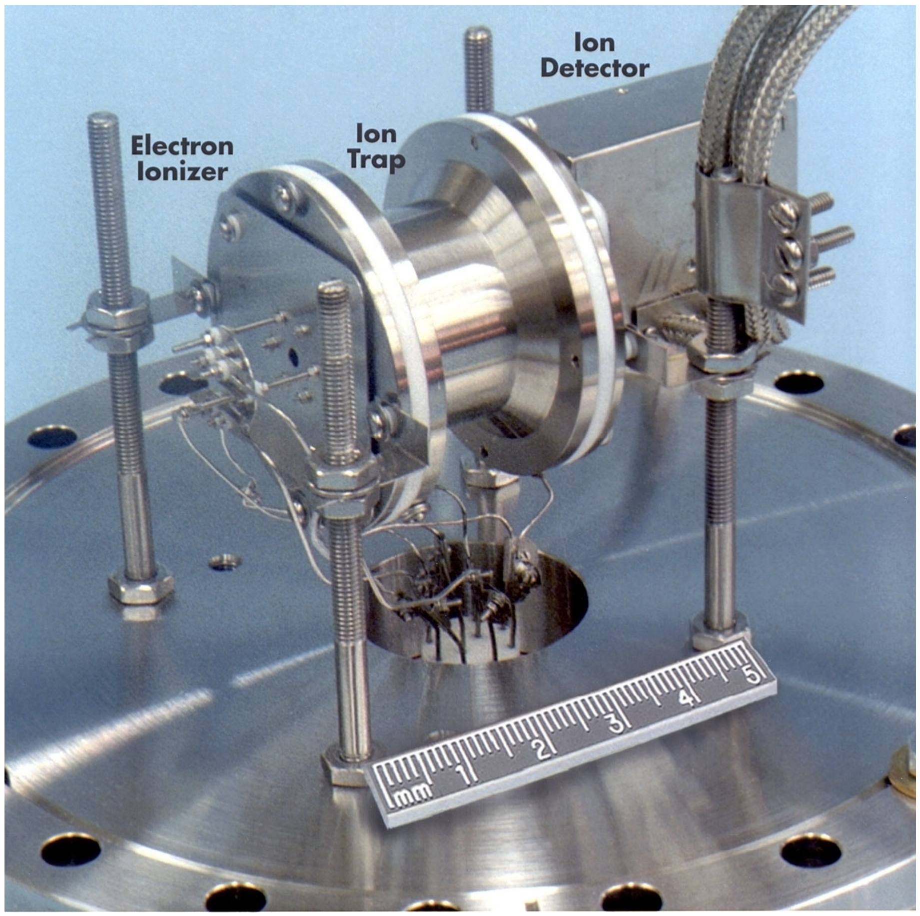
The Quadrupole Ion Trap Mass Spectrometer



Quadrupole ion trap and Quadrupole mass filter invented by Paul and Steinwedel in 1960

W. Paul awarded Nobel Prize in Physics 1989

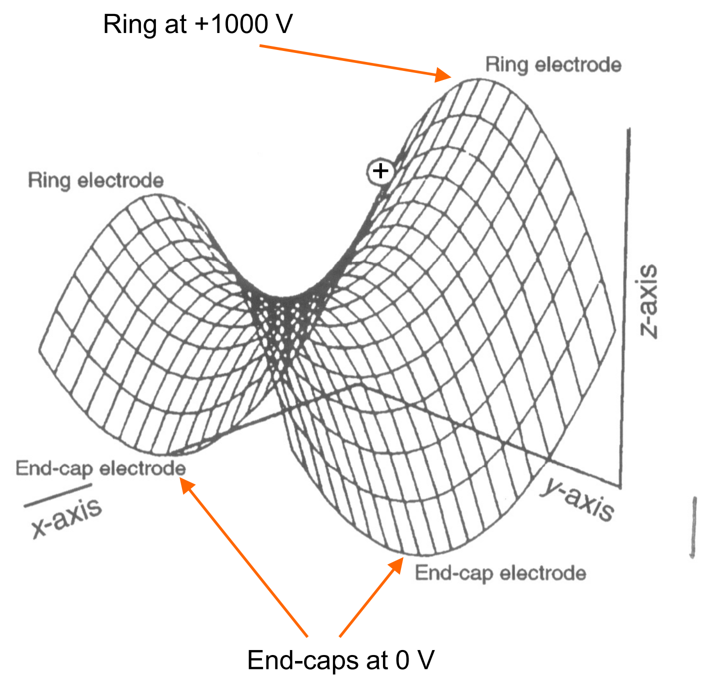
How does the trapping really work?

Consider applying a voltage to the ring electrode

Say 1000 $V_{0\text{-}P}$ at 1 MHz

Create an ion in this quadrupole field

Pause and look at potential surface



Ion rolls down slope to trap center = radial focusing

Ion reaches trap center, can continue downhill =

axial defocusing

Restart voltage, ring at -1000 V end-cap at 0 V, rotate figure by 90°

Get axial focusing and radial defocusing

Balance focusing and defocusing forces – can trap the ion!

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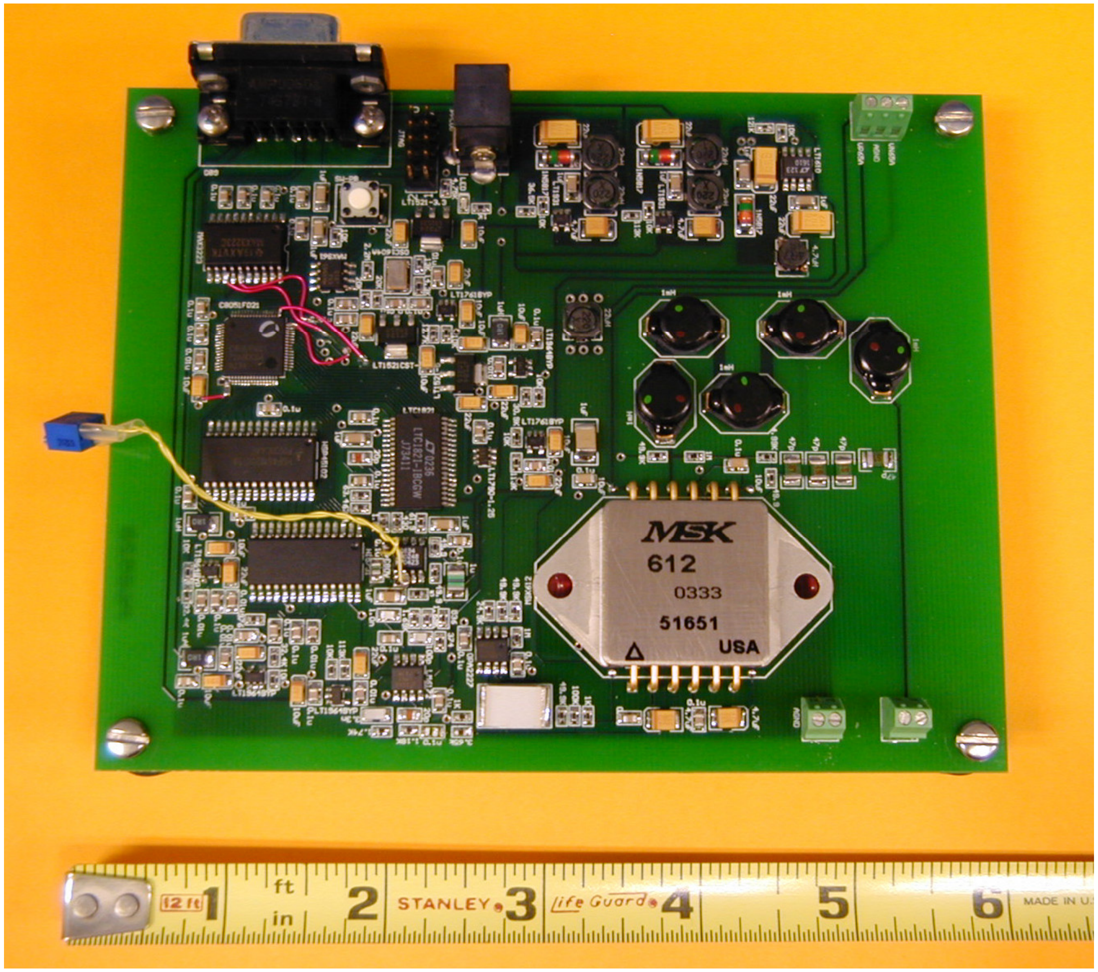
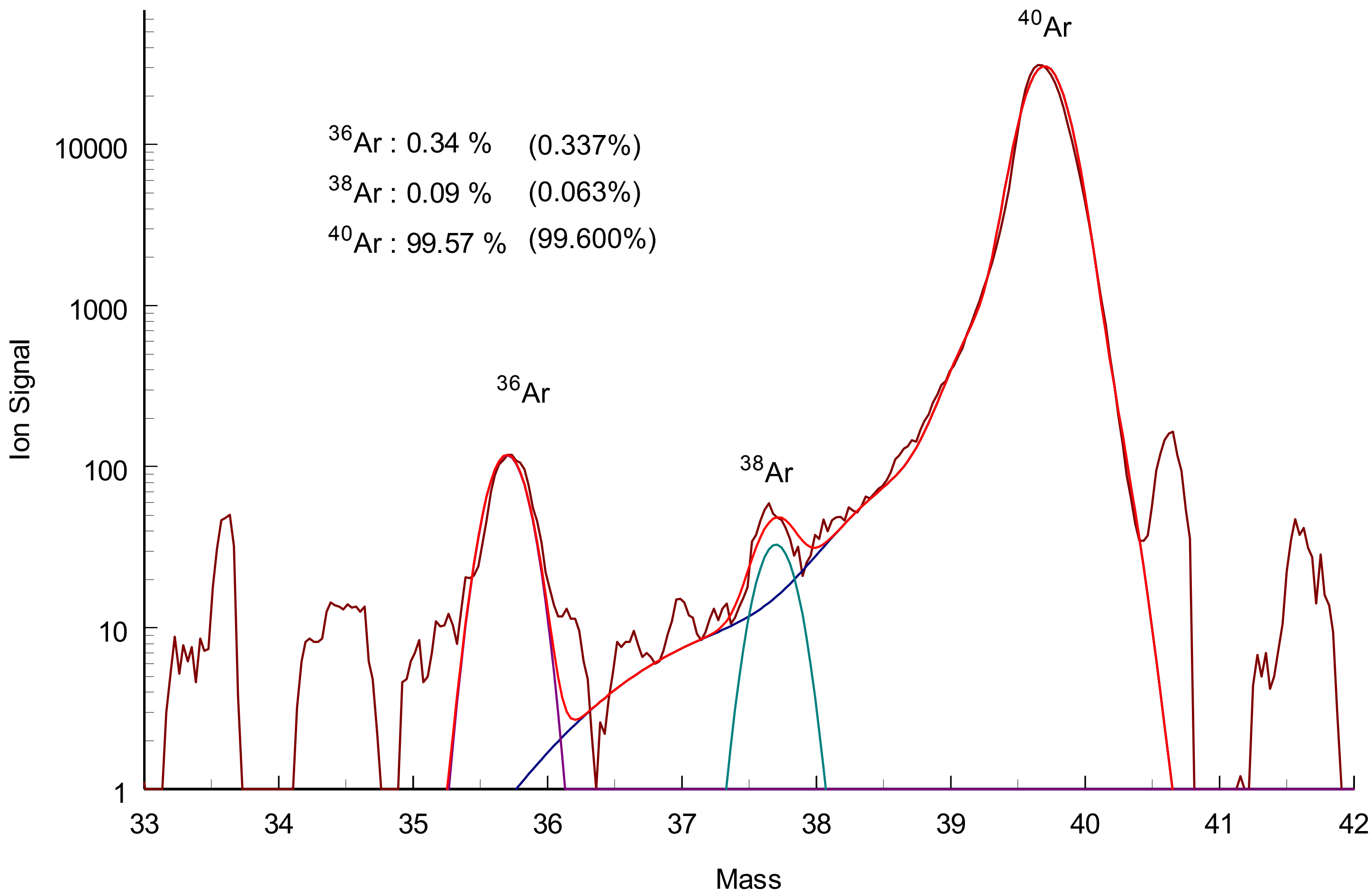
Miniaturization: Board-Level RF Electronics for Driving a QMSA or Paul Trap

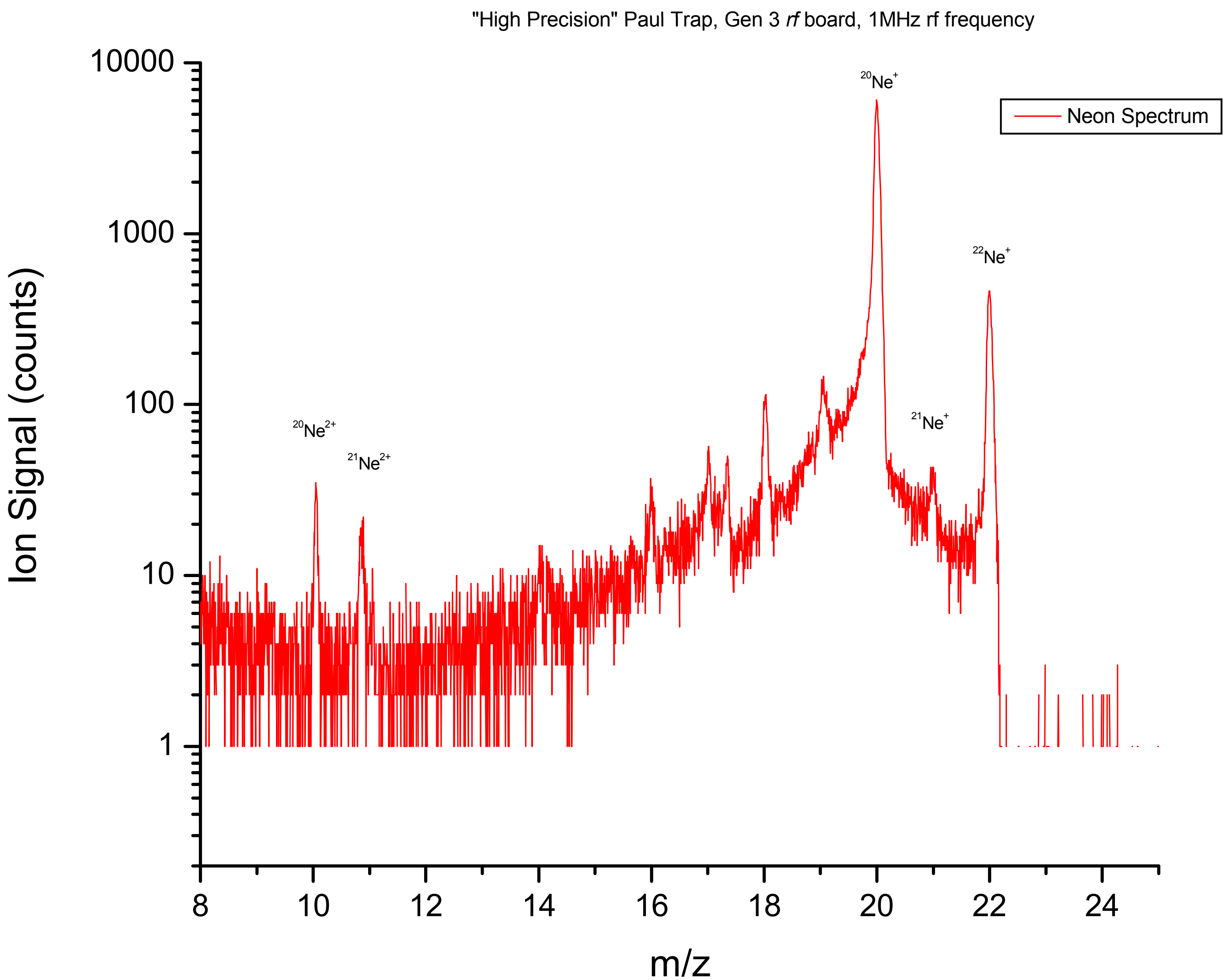


Further miniaturization to a System-on-a-Chip (SoC) is proceeding.

Argon Isotopes with Paul Trap and Digital RF Board



Isotope Ratios for Neon



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How do we balance the forces?

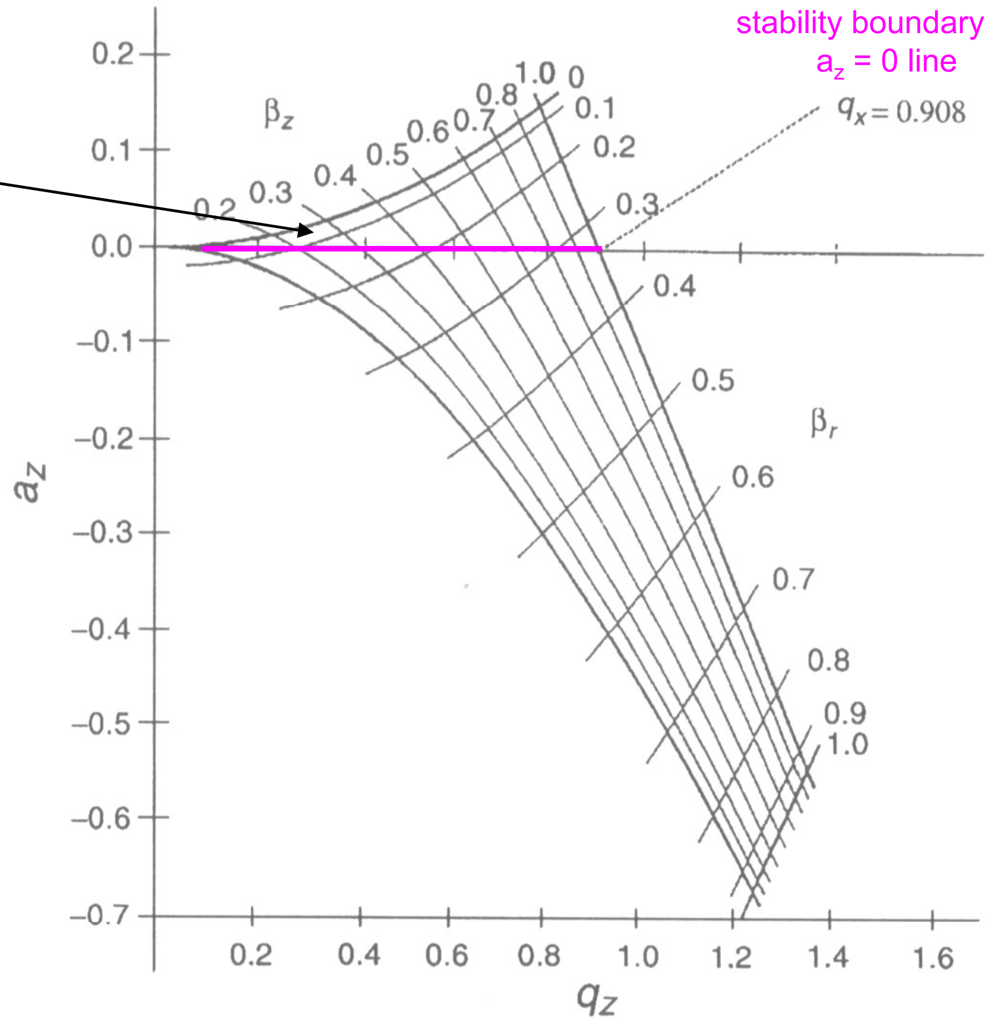
In practice *U* = 0 → $a_z = 0$;

operate along this line

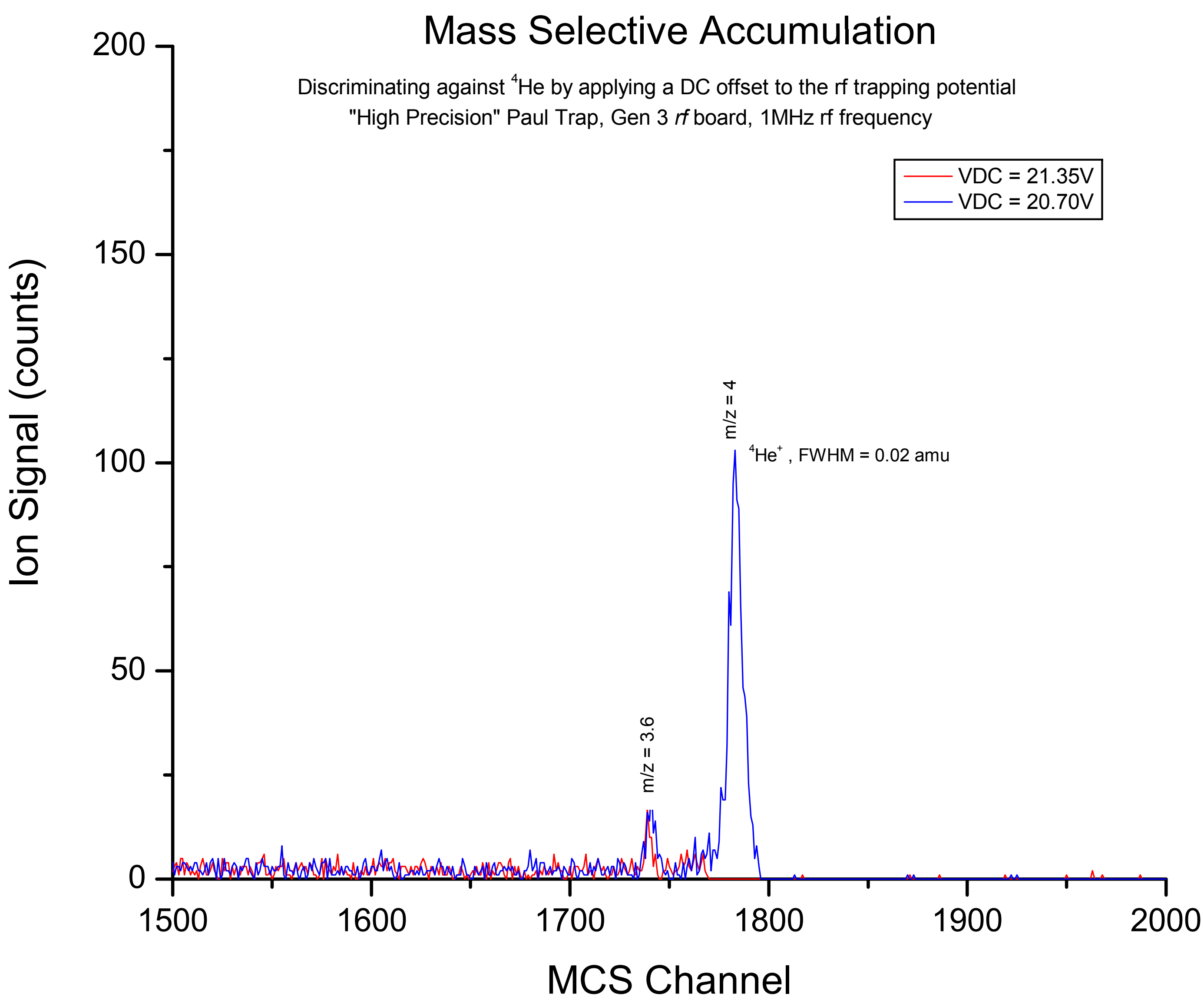
$$q_z = \frac{4eV}{m r_0^2 \Omega^2}$$

$$-a_z = \frac{8eU}{m r_0^2 \Omega^2}$$

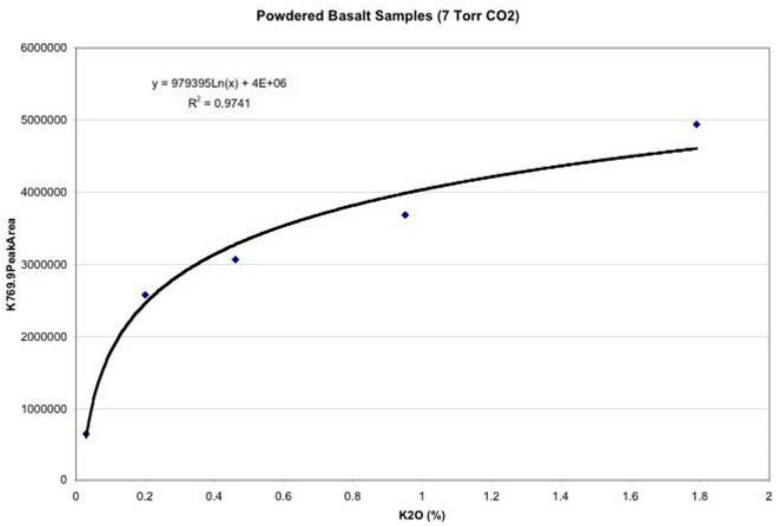
Can see that for $a_z = 0$ the stable/unstable boundary occurs at $\mathbf{q_z = 0.908}$.



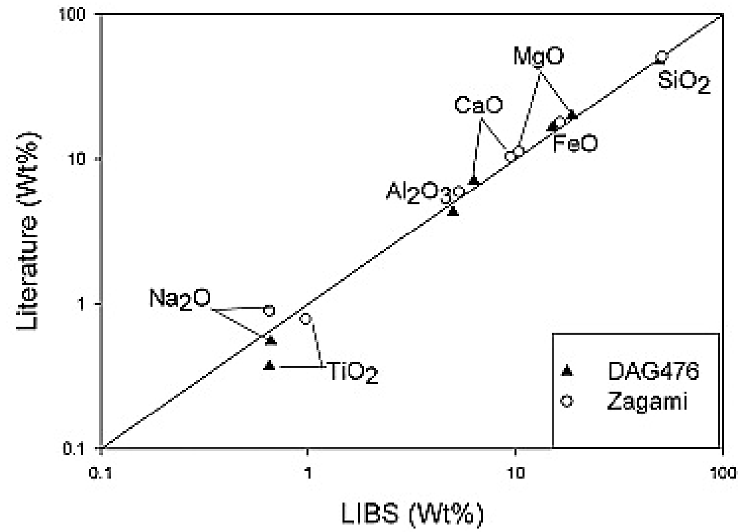
Mass Discrimination by DC Offset on Trap Ring



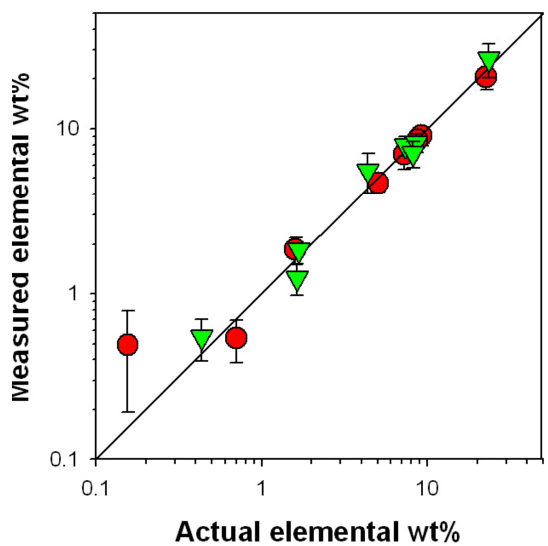
Elemental Abundances with the LIBS



(a) LIBS calibration for K in basalts, at 7 torr pressure.



(b) Comparisons with two martian meteorites.



(c) Blind test comparison of LIBS (solid line) to actual abundances for two “unknown” basalt samples.

Progress Summary

Sample Introduction and Heating

- *developed a 6-armed sample loading mechanism*
- *developed a resealable (elastomer) vacuum chamber*
- *developed radiatively-heated sample oven for operation to 1500 C*

Laser-Induced Breakdown Spectroscopy (LIBS)

- *conducted lab & field tests of a high- and low-resolution spectrograph*
- *tested a suitable Nd:YAG Q-switched laser (1 Hz, 6-10 ns, 20-25 mJ/pulse)*
- *quantitatively detected K and other elemental abundances in minerals*

Miniature Quadrupole and Paul Trap MS

- *assembled and tested a QMSA system to interface to the sample oven*
- *designed & tested a new-type digital RF generator board with excellent control of frequency and THD*
- *using the Paul Trap, demonstrated good isotope separation for the gases* $^{20,21,22}Ne^+$, $^{36,38,40}Ar^+$, $^{32,34}S^+$, *and* $^{83,84}Kr^+$
- *demonstrated static operation of a commercial RGA with loading from sample oven*
- *demonstrated sensitivity to* 10^{-12} *torr* P_{Ar} *with RGA, at* 10^{-9} *torr total background pressure*
- *characterized background evolution of Ar from oven while cold, and while hot (& empty).*